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TRAINING PROCEDURES FOR MAP LEARNING.(U)

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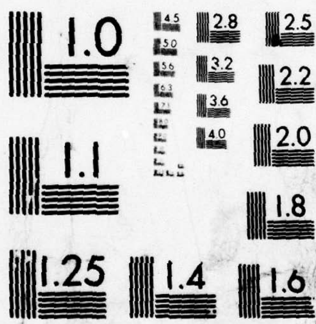

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TRAINING PROCEDURES FOR MAP LEARNING.

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Perry W. Thorndyke and Cathleen Stasz

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PREFACE

This study is the second in a series of Rand investigations of the process of map learning. The work reported here was performed between September and December 1978 and was supported by the Personnel and Training Research Programs of the Office of Naval Research. Additional research in this area is continuing and will be documented in subsequent reports.

SUMMARY

This study investigated the influence of subjects' high-level study procedures on their success at learning a map. After learning a map using their own techniques, subjects were instructed (a) in the use of six previously determined effective learning procedures, (b) in the use of six procedures unrelated to learning success, or (c) to continue using their own techniques. The effective-procedures set comprised three techniques for learning spatial information, two techniques for using self-generated feedback to guide subsequent study behavior, and a procedure for partitioning the map into sections. On a second map-learning task, subjects trained to use effective procedures improved their performance significantly more than subjects in the other two groups. The magnitude of the performance increment was a function of the frequency with which these subjects used the designated procedures. In addition, both subjects' map-learning performance and subjects' use of spatial learning procedures were predictable from a psychometric measure of visual memory ability. These findings suggest that high-level procedures and low-level processing skills play complementary roles in determining complex task performance.

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I. INTRODUCTION

Individual differences among learners constitute an important source of variation in many learning and memory tasks. One source of individual differences often studied by educational psychologists is the variation in the basic skills required to perform the experimental task (Snow, 1976; Cronbach & Snow, 1977). Researchers have recently begun to consider another potential source of differences in complex task performance: the procedures that subjects use to perform the task (e.g., Johnson, 1978; MacLeod, Hunt, & Mathews, 1978). In a study of map learning, Thorndyke and Stasz (1979) found that successful learners differed from poor learners in the high-level processing procedures they used when attempting to learn a map. Several of the procedures used primarily by good learners required them to encode spatial configurations of information from the map. This suggested the possibility that spatial ability, not procedure selections, might underlie the observed individual differences in performance. The hypothesis that abilities, not procedures, primarily account for individual differences has received support in studies of short-term retention in other paradigms (Huttenlocher & Burke, 1976; Cohen & Sandberg, 1977; Lyon, 1977).

In the present study, we investigate the hypothesis that subjects can significantly improve their map-learning performance, independent of their basic abilities, by using effective processing procedures. By training subjects in the use

of certain processing procedures correlated with success in the earlier study (Thorndyke & Stasz, 1979), we hoped to improve their performance over that of subjects of equivalent abilities using self-selected procedures. Since the results of the earlier study guided our selection of procedures for the present study, we briefly summarize the results of that experiment here.

To identify the procedures subjects use to learn a map, we analyzed verbal protocols of subjects who were trying to memorize two maps. Subjects were either experienced or novice map users. They studied a map for two minutes, during which time they provided verbal protocols describing what information they were focusing on and the procedures they were using to learn that information. After the study period, subjects drew as much of the map as they could remember. Six such study-recall trials were provided on each of two maps (shown in Figures 1 and 2).

Analysis of subjects' protocols and recall performance revealed that a variety of performance differences could be traced to differences in processing procedures. Good learners frequently used procedures that were rarely used by poor learners. Success depended more on the use of particular procedures than on subjects' prior experience using maps. Experienced map users were either successful or unsuccessful map learners, depending on the procedures they adopted during study. Table 1 shows the correlations between the frequency of use of selected procedures and the percentage of map elements correctly recalled, averaged across maps. A map element corresponded to

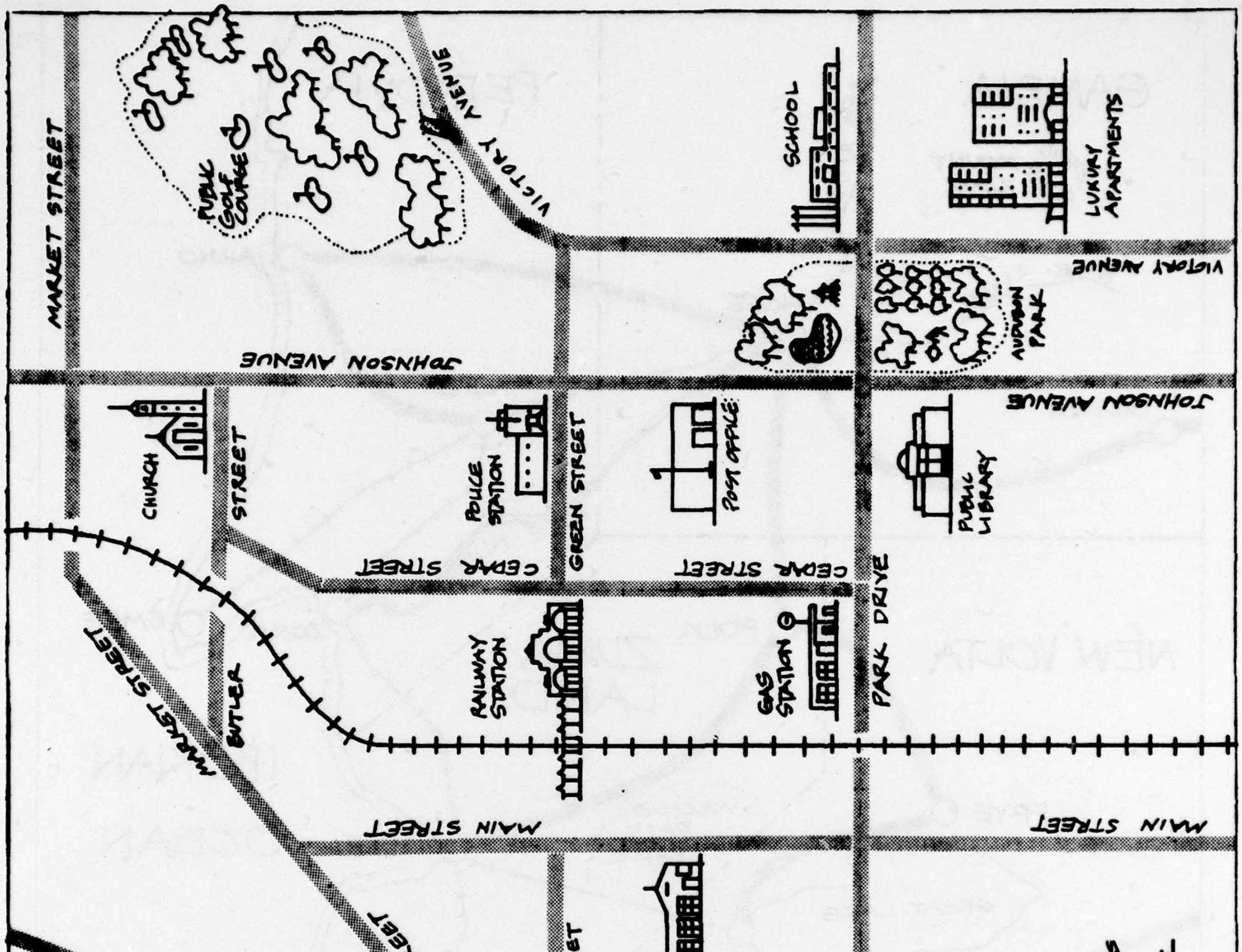

Figure 1. Town Map

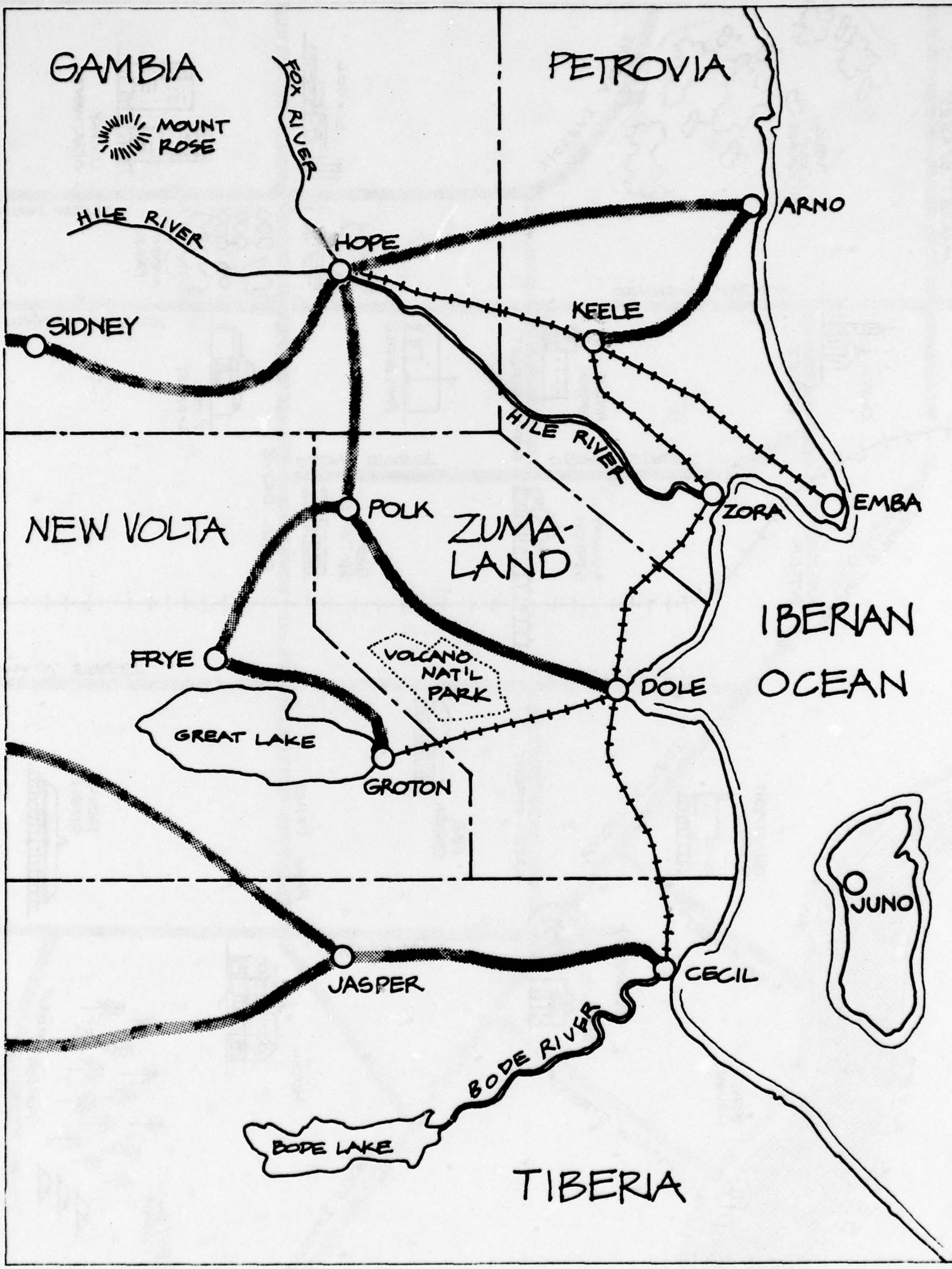

Figure 2. Countries Map

the name plus location of a single conceptual entity, such as a building, a road, a river, or a country.

Table 1

Correlations between Strategy Use and Recall (after Thorndyke & Stasz, 1979)

Strategy	Correlation with Recall
Imagery	.66 *
Evaluation of unlearned information	.61 *
Relation encoding	.57 *
Rehearsal	.54 *
Pattern encoding	.50 *
Memory-directed sampling	.46 *
Partitioning	.31
Labeling	.14
Mnemonics	-.17
Association	-.29

* $p < .05$

We supplemented these correlational data by contrasting the learning protocols of good learners and poor learners. We defined good learners as subjects who recalled at least 90% of the map elements correctly by the last trial. By comparing the protocols from the two groups, we isolated six seemingly effective procedures: partitioning, memory-directed sampling, imagery, pattern encoding, relation encoding, and evaluation. Because these six procedures play an important role in the present study, a brief description of each follows.

Partitioning is a procedure for focusing attention on a subset of the map information. Since each map contained too much information to be learned on any one trial, some learners defined meaningful subsets of the information on which to focus attention. Subjects partitioned the map in two ways: by attending only to elements in a particular spatial region (e.g., the northwest corner of the map) or by attending only to elements in a particular conceptual category (e.g., streets).

A subject using memory-directed sampling would construct a mental list of the information that was not recalled during a given recall attempt. On the next study trial, the subject would immediately search for and study that unlearned information.

Imagery involved the construction in memory of a visual image of some portion of the map. For example, subjects might form a mental image of the shape of the coastline in the map shown in Figure 2. Subjects would often exhibit the use of this procedure by closing their eyes or by looking away from the map during the study period.

Pattern encoding required the explicit encoding of a spatial detail or shape of a single map element. For example, a subject might notice that a road curved to the north halfway along its length.

The relation encoding procedure was used to encode detailed spatial relationships between two or more objects. For example, a subject might encode the location of a building as a particular street intersection or notice that two streets were parallel.

Subjects' use of evaluation involved monitoring their learning progress by considering what information they had already learned and what still needed to be studied. Good learners primarily focused attention on and evaluated unlearned elements, ignoring that information they had already learned. The procedure shown in the second row of Table 1 represents the percentage of all evaluation statements that concerned as-yet-unlearned, rather than already learned, map elements.

In sum, good learners structured the learning task by defining and systematically studying subsets of information from the map (partitioning and memory-directed sampling). They used encoding procedures that were particularly adaptive for learning spatial information (imagery, pattern encoding, relation encoding). Finally, they evaluated their learning progress consistently and accurately, using the outcome of those evaluations to guide their study behaviors (evaluation, memory-directed sampling).

While these high-level processing procedures were correlated with learning outcomes, such procedures are but one of several potential sources of individual differences on this task. It is not clear what role the use of these procedures alone plays in learning. While some studies have shown that learning can be improved through the use of such procedures as imagery (Paivio, 1971; Rohwer, 1973) or chunking (Bower & Winsenz, 1969; Belmont & Butterfield, 1971; Hunt & Love, 1972; Estes, 1974), other studies

have demonstrated that individual differences remain even when such procedures are precluded (Huttenlocker & Burke, 1976; Lyon, 1977).

Hunt (1978) has proposed that individual differences in cognition arise from three sources: differences in the use of simple processing procedures, differences in knowledge related to or about the task, and differences in the low-level mechanics of information processing. Differences in subjects' profiles of procedure use clearly differentiated good from poor learners in the Thorndyke and Stasz (1979) study. On the other hand, the failure of experienced map users to perform consistently better than novice map users suggests that knowledge about maps was not a source of performance differences. The third source of individual variation, the mechanics of information processing, refers to basic operations performed on the physical representation of a symbol. These operations are presumed independent of the information denoted by the symbol. Such operations include decoding, visualization, selective filtering, memory retrieval, and memory comparison. Numerous studies have demonstrated individual differences in these operations on a variety of tasks (e.g., Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975; Cohen & Sandberg, 1977; Lyon, 1977; Goldberg, Schwartz, & Stewart, 1977).

Thorndyke and Stasz did not measure these operations directly, but it seems reasonable to assume that subjects differed in their abilities to carry out these processes.

Differences at this level of processing typically impact on high-level procedure choices (MacLeod, Hunt, & Mathews, 1978). For example, on the map-learning task, subjects differing in self-reported visualization ability employed different procedures. The best map learner stated that he had good visual memory and frequently constructed visual images to learn and remember information. By contrast, the worst learner reported that he had very poor memory for spatial information and had never experienced having mental images. This learner used primarily verbal procedures and did not attempt to learn the more complex spatial configurations on the maps. Furthermore, in another study of map learning (Stasz & Thorndyke, 1979), two psychometric measures (visual memory ability and field-dependence) correlated highly with both performance on the task and the use of strategies that depended on visual and spatial-analytical processing.

These studies suggest that both higher-level procedure choices and basic processing abilities contribute to differences among individuals. The present study was designed to investigate whether subjects could be trained to use a set of successful processing procedures for learning information from maps and whether such training alone would significantly improve their performance. The set of "effective" techniques comprised three procedures for learning spatial information (imagery, pattern encoding, relation encoding), two procedures for using self-generated feedback to guide subsequent study behaviors (memory-directed sampling, evaluation), and a procedure for dividing the learning problem into subproblems (partitioning).

To contrast training in the use of effective procedures with the effects of instruction per se, we included subjects who received training on six procedures uncorrelated with performance in our previous study. These procedures were mnemonics, labeling, rehearsal, and three association procedures. Correlations between performance and the use of these procedures are presented in Table 1. The mnemonic procedure requires the creation of an acronym to represent the names of several map elements. For example, "SHAK" is a mnemonic for the city names of Sidney, Hope, Arno, and Keele on the Countries Map. The labeling procedure requires the generation of a concept or name for a complex spatial configuration as a cue for recall. For example, a subject might notice that the coastline on the Countries Map forms the profile of a face. The rehearsal procedure entails the repetition of a set of names or location descriptions. In the previous study (Thorndyke & Stasz, 1979), one good learner rehearsed the names of the map elements while imaging the spatial relationships of those elements. This combined use of rehearsal and imagery produced the high correlation between rehearsal and recall shown in Table 1. In a subsequent study (Stasz & Thorndyke, 1979), rehearsal was unrelated to performance. The three association procedures establish conceptual relations between two or more map elements. The first association procedure consists of creating a link between some map information and some related prior knowledge. For example, the subject might notice that Market Street on the Town Map is

spatially similar to Market Street in San Francisco. A second type of association relates two or more objects from the map, using some additional world knowledge. For example, one might link Victory Avenue with the adjacent golf course through the association "Victory at golf." A third use of this general procedure requires the creation of a narrative or scenario incorporating several map elements (e.g., "The BUTLER went to CHURCH and saw CEDAR trees in the PARK."). Since these procedures were uncorrelated with success in our prior studies, training subjects to use them should not affect their performance.

We also assessed the visual memory ability of subjects using the Building Memory test from the Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, & Harmon, 1976). This test measures subjects' ability to remember the configuration, location, and orientation of spatial information in a complex display. If visual memory accounts for much of the variation in learning, or if it is a prerequisite for using high-level procedures, then training should have little effect on performance.

II. METHOD

MATERIALS

The Town Map, shown in Figure 1, served as the pre-training experimental material. It contained a river, streets, buildings, parks, and other landmarks typically found in a small town. All of these map elements except the railroad tracks had verbal labels or names associated with them. The Countries Map, shown in Figure 2, served as the post-training test material. It differed from the Town Map in both scale and content. This map portrayed countries, cities, roads, railroads, and prominent terrain features, such as an ocean, an island, rivers, lakes, and a mountain. Roads and railroads had no verbal labels, but all other map elements were named. In constructing these maps we attempted to include a variety of types of map information and to make the maps as natural as possible. A third map, adapted from a study by Shimron (1975), was used by subjects during training to practice their learning procedures. This County Map depicted an imaginary county containing roads, cities, a river, and mountains.

SUBJECTS

Forty-three subjects participated in the study. Thirteen were Santa Monica Community College students who were paid $3.50 per hour. Thirty subjects were UCLA undergraduates who participated in order to fulfill a course requirement.

DESIGN

Subjects were randomly assigned to either the control group or one of two training groups. The Effective Procedures group (n=14) received instruction on six procedures correlated with successful learning in our previous studies. These procedures were partitioning, imagery, pattern encoding, relation encoding, memory-directed sampling, and evaluation. The Neutral Procedures group (n=16) received instruction on six procedures that were previously uncorrelated with performance: mnemonics, spatial labeling, rehearsal, and three association procedures. The No Procedures group (n=13) received no training.

PROCEDURE

Within each treatment condition subjects were tested in groups. They were told that the study investigated the effectiveness of certain procedures for learning maps and that their task was to learn, using any techniques they knew, the map they would be shown. Each subject was then given a copy of the Town Map to study. After two minutes the map was withdrawn and subjects were instructed to draw as much of the map as they could remember. Recall time was limited to seven minutes. Three study-recall trials, administered in this manner, served as a pretest of map learning.

Following these trials, each group received different instruction on the use of learning techniques. For the Neutral and Effective Procedures groups, the experimenter described each

of the respective procedures for that group in detail. Instructions for the use of the evaluation procedure emphasized, in addition to the technique itself, the advantages of accuracy, attention to unlearned elements, and subsequent study of those elements. The experimenter illustrated the use of each procedure with examples on the Town Map. Subjects studied these examples on their own copies of the map.

Subjects in the No Procedures group were instructed to continue using their own learning techniques on the next maps. In addition, the experimenter provided some general suggestions for improving performance on subsequent maps. She urged subjects (a) to concentrate on the task and not to be distracted, (b) to evaluate the effectiveness of the techniques they were using, (c) to discontinue using any techniques that appeared to be ineffective, and (d) to try to learn as much as possible in the time provided. For all three groups, this training session lasted between 20 and 30 minutes.

Subjects were then given copies of the County Map and instructed to practice the techniques that they had been taught. Two trials, consisting of two minutes of study and five minutes for recall, were provided. Following these practice trials, the experimenter reviewed the learning procedures and answered any questions about their use. Subjects were then given copies of the Countries Map and instructed to use the techniques they had been taught whenever possible. Subjects alternately studied and

reproduced the map on five study-recall trials. Two minutes were provided for each study trial, seven minutes for recall.

After the last recall trial, subjects completed two questionnaires reporting the procedures they used during study. Each questionnaire comprised 16 questions, each of which required subjects to indicate the frequency with which they used a particular procedure. Nine of the 16 questions referred to the effective learning procedures, and six questions referred to the neutral procedures. One question referred to a procedure not in either set. For each question, a statement describing the procedure was followed by an example of its use on the appropriate map. Subjects rated how often they used the procedure on a scale ranging from "0" (never used the procedure) to "6" (used procedure on every trial). Figure 3 illustrates a procedure question for each map. Question 1 refers to the partitioning procedure, Question 2 to one of the association procedures. Subjects consulted their maps while answering all questions. Following completion of the questionnaire, subjects took the psychometric test of visual memory ability. Total training and testing time for each group was approximately two and one-half hours.

1) I divided the map into smaller sections or parts and concentrated on learning the information in each smaller part.

Example: Tried to learn all the information located in the area above Market Street in the northwest corner of the map.

Circle the number which indicates whether or not and how often you used this strategy.

0	1	2	3	4	5	6
NEVER	ONCE/ONE TRIAL	OCCASION-ALLY	FREQUENTLY	MOST OF THE TIME	EVERY TRIAL

2) I tried to learn certain information by associating it in some way to my experience or to other facts that I know.

Example: The map reminded me of Africa. There is a country in Africa called Zambia, which is similar to Gambia.

Circle the number which indicates whether or not and how often you used this strategy.

0	1	2	3	4	5	6
NEVER	ONCE/ONE TRIAL	OCCASION-ALLY	FREQUENTLY	MOST OF THE TIME	EVERY TRIAL

Figure 3. Examples of Strategy Questions for the Town Map and the Countries Map

III. RESULTS AND DISCUSSION

Each map that subjects recalled was scored for percent correct reproduction of map elements (e.g., buildings, roads, countries, lakes, parks, etc.). An element could have two attributes: a spatial location and a verbal label. The Town Map contained 33 elements, all but one of which were labeled. The Countries Map contained 43 elements, 26 of which had names and 17 of which were unlabeled. The County Map was used only for practice and was not scored for recall.

Recall of spatial and verbal information was scored separately using the decision rules described in Thorndyke and Stasz (1979). For each subject, the proportions of verbal attributes, spatial attributes, and entire elements correctly recalled were computed for each trial. An overall score for each map was obtained by computing the mean across recall trials. Scores for the Town Map represent the mean recall across three learning trials; scores on the Countries Map represent recall across five trials.

PRE-TRAINING PROCEDURE USE

We were first interested in the relationship between procedure use and learning performance before training. Therefore, we divided the 43 subjects into good and poor learners based on performance on the first map. We defined good learners as subjects whose last trial recall was at least 45% and whose

mean recall across trials was at least 34%. Poor learners all had last-trial performance of less than 40% and mean recall of less than 32%. These criteria produced a group of 20 good learners and a group of 20 poor learners. Three subjects who could not be unambiguously classified were discarded from this analysis.

Table 2

Comparison of Pre-Training Performance and Procedure Use for Good and Poor Learners

Variable	Good Learners (N=20)	Poor Learners (N=20)
Mean Percent Recall per Trial		
Complete elements	45.05**	20.20
Spatial attributes	48.20**	26.10
Verbal attributes	74.30**	52.15
Mean Frequency Rating of Procedure Use		
Effective Procedures		
Partitioning	3.24*	2.25
Memory-directed sampling	4.96	4.37
Evaluation	4.00	3.82
Imagery	5.05*	4.12
Pattern encoding	4.90**	3.68
Relation encoding	4.46**	3.04
Neutral Procedures		
Mnemonics	1.14	1.79
Spatial labeling	2.18	1.98
Rehearsal	4.52	4.70
Association 1	2.10	1.81
Association 2	0.35	0.75
Association 3	1.44	1.15

* $p < .05$
** $p < .01$

Table 2 contrasts these groups on reported use of the twelve procedures trained in this experiment. Differences between groups were evaluated using one-tailed *t*-tests. As the first three rows of Table 2 show, good learners were superior in recall of complete elements, spatial attributes, and verbal attributes. These learners also tended toward more frequent use of the "effective" procedures. While good and poor learners did not differ in their frequency of use of the evaluation procedure, good learners used four of the other five Effective Procedures significantly more often than did poor learners. In contrast, good and poor learners did not differ in their use of the Neutral Procedures. These results replicate the differences between good and poor learners reported by Thorndyke and Stasz (1979) and further indicate the efficacy of the effective learning procedures.

EFFECTS OF TRAINING

To determine the effects of instruction on the use of these procedures, we compared the pre-training and post-training scores for subjects in the three groups. Separate analyses of variance were performed for recall of complete map elements, recall of spatial attributes, and recall of verbal attributes. Figure 4 shows the data for recall of complete map elements. Overall, the mean recall score for the second map was greater than that for the first map, $F(1,40) = 71.31$, $p < .001$. The main effect for the training group was not significant ($F < 1$). More importantly, however, the predicted map-by-treatment interaction

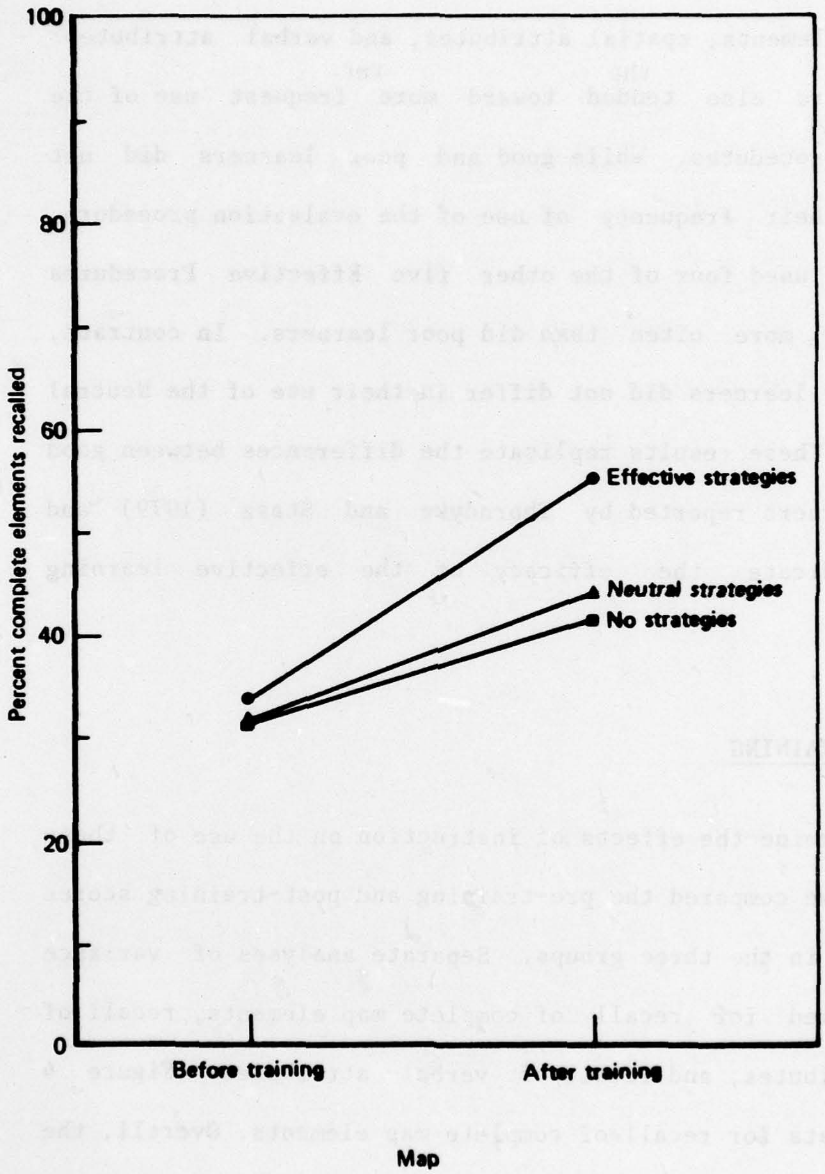

Figure 4. Recall of Complete Map Elements

was reliable, $F(2,40) = 3.32$, $p < .05$. A planned comparison confirmed that the Effective Procedures group recalled more on the post-training map than the Neutral Procedures and No Procedures groups, $t(80) = 4.49$, $p < .001$.

Figure 5 displays the results for recall of spatial and verbal attributes. Recall of spatial attributes (part A) improved from the first to the second map, $F(1,40) = 70.27$, $p < .001$. While group differences were in the expected direction, the interaction fell short of significance, $F(2,40) = 1.81$. However, a planned comparison indicated that the Effective Procedures group recalled more on the post-training map than the other two groups ($t(80) = 3.48$, $p < .001$). In contrast, recall of verbal attributes was nearly identical across maps and groups (part B).

To further explore the group differences on the post-training task, performance on the second map was analyzed by trial. Figure 6 presents the data for complete element recall. While the Effective Procedures group was superior on all trials, the main treatment effect was only marginally reliable, ($F(2,160) = 2.38$, $p < .10$), and the interaction was not significant, ($F(8,160) = 1.04$). However, as Figure 6 shows, the Effective Procedures group showed a marked improvement in recall after trial 2 relative to the other groups. Post-hoc comparisons declared the means for the Effective Procedures group to be

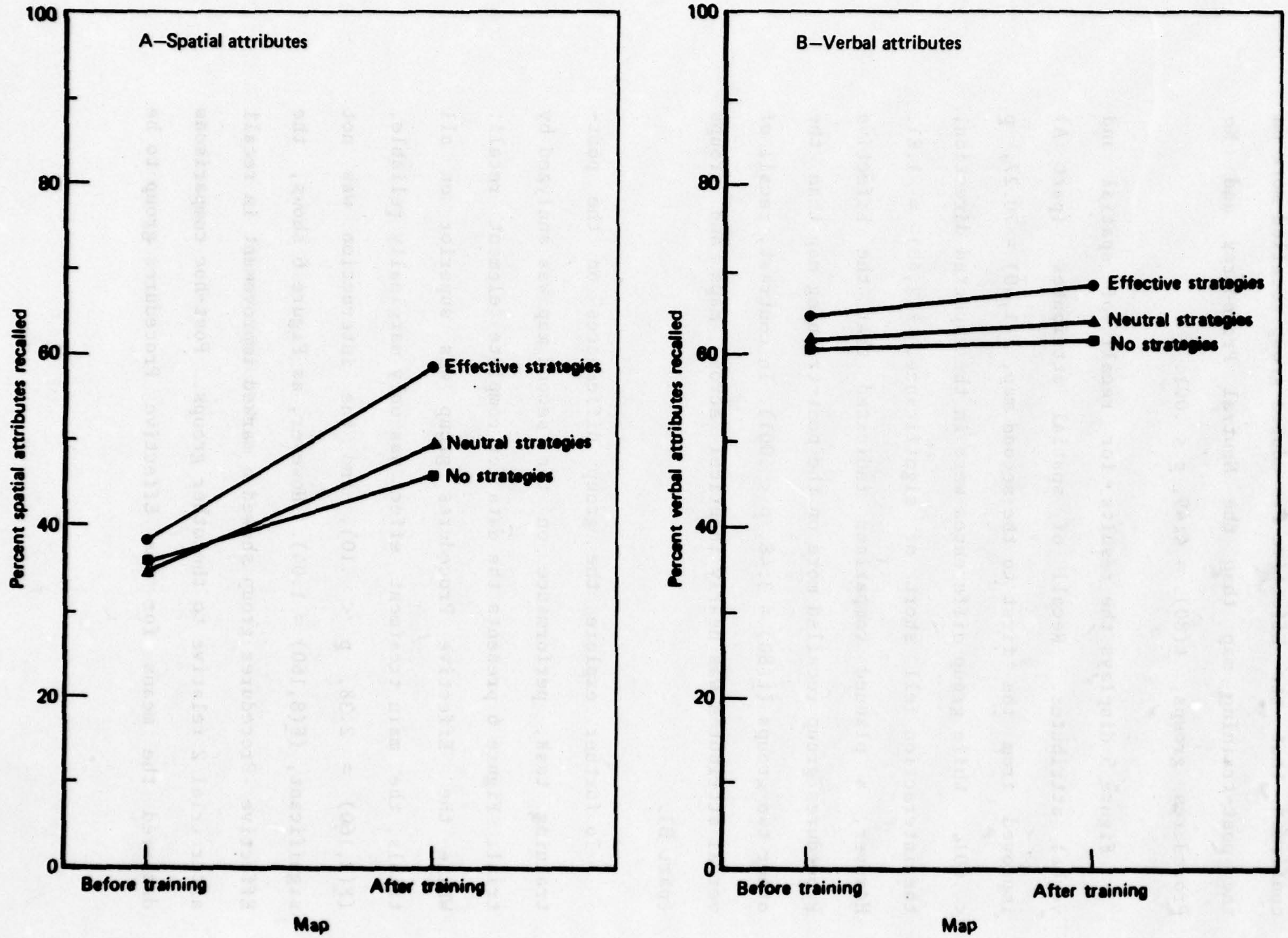

Figure 5. Recall of Spatial and Verbal Attributes of Map Elements

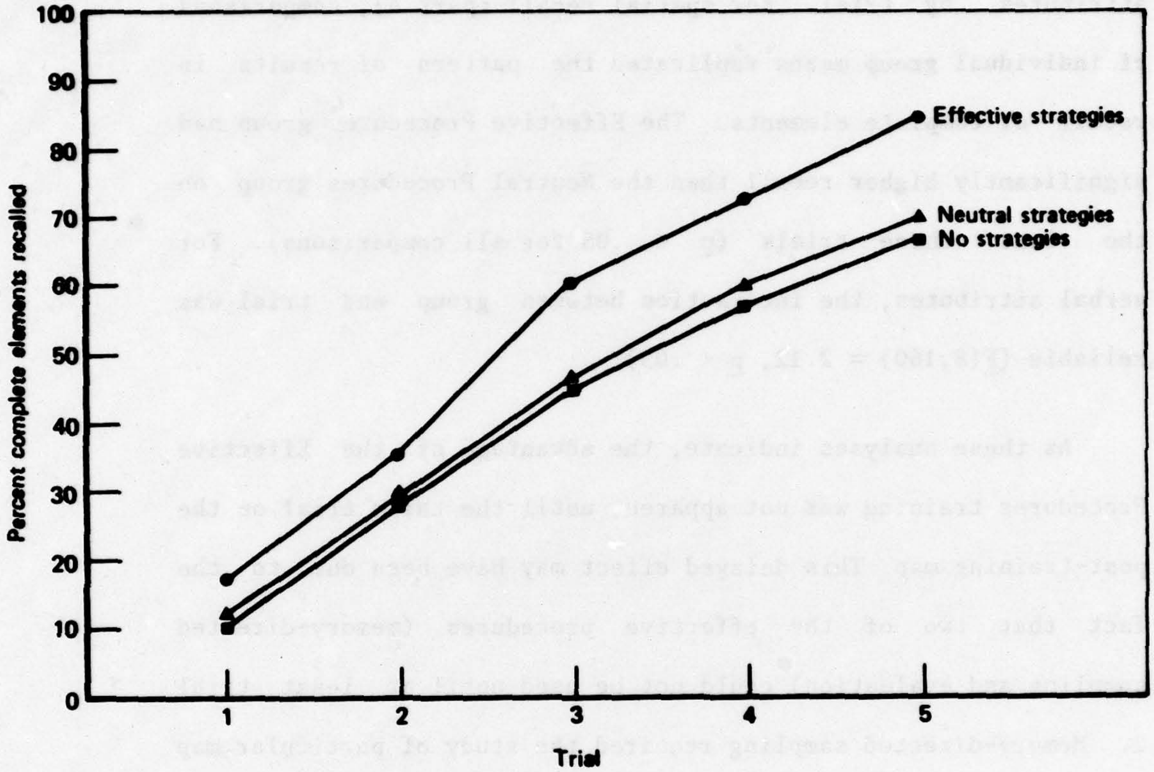

Figure 6. Recall of Complete Elements on Post-Training Map

larger than those for the Neutral Procedures group at trials 3, 4, and 5 ($p < .01$ for all comparisons).

Figure 7 presents the data for recall of spatial and verbal attributes by trial. For spatial recall (part A), comparisons of individual group means replicated the pattern of results in recall of complete elements. The Effective Procedures group had significantly higher recall than the Neutral Procedures group on the last three trials ($p < .05$ for all comparisons). For verbal attributes, the interaction between group and trial was reliable ($F(8,160) = 2.12$, $p < .05$).

As these analyses indicate, the advantage of the Effective Procedures training was not apparent until the third trial on the post-training map. This delayed effect may have been due to the fact that two of the effective procedures (memory-directed sampling and evaluation) could not be used until at least trial 2. Memory-directed sampling required the study of particular map information on trial n that had not been recalled on trial n-1. Evaluation required subjects to compare perceived map information on trial n to their recall of that information on trial n-1. In addition, these techniques are most effectively employed when much of the map has already been learned. Therefore, these procedures may not have been used extensively until later trials.

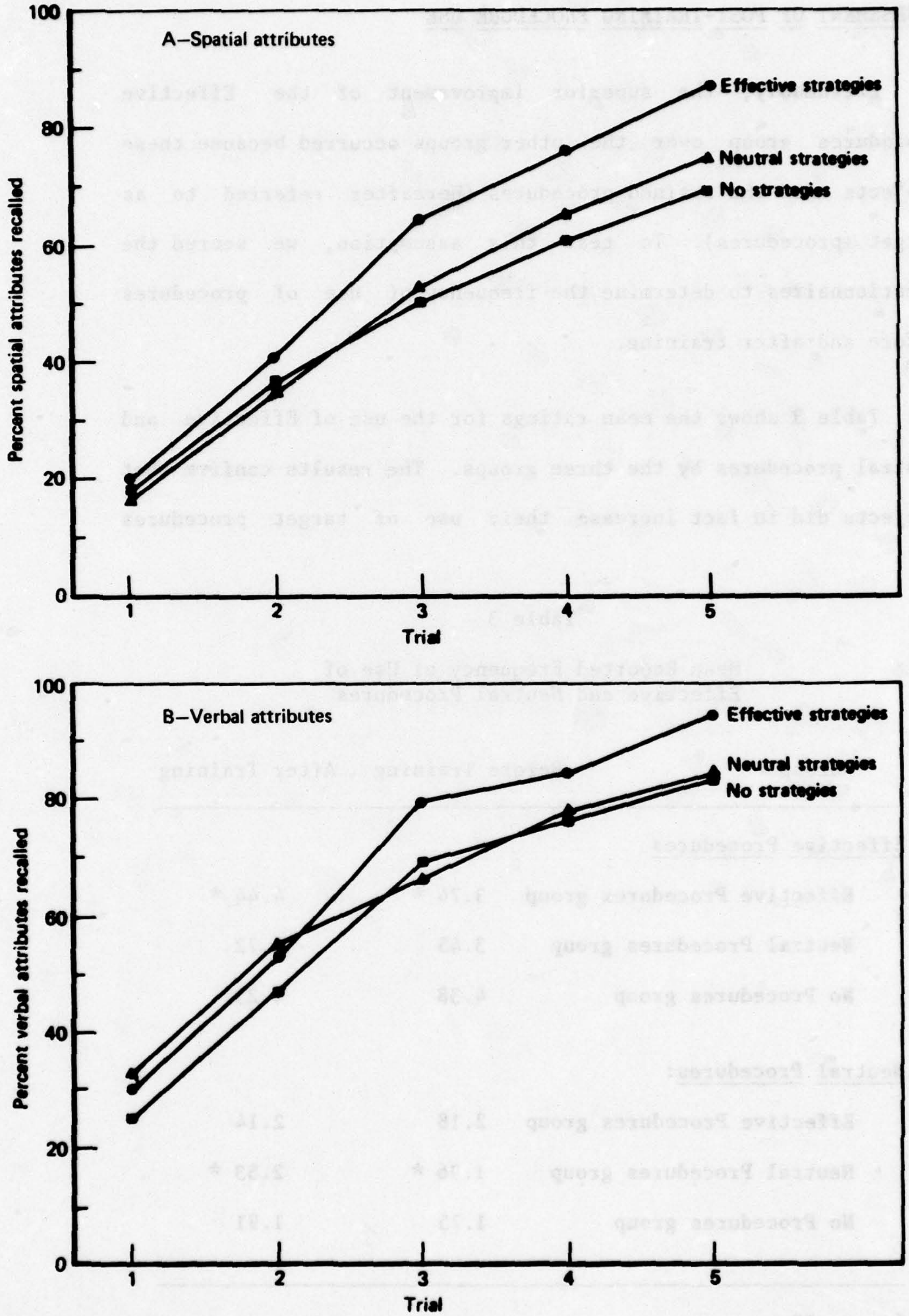

Figure 7. Recall of Spatial and Verbal Attributes of Map Elements on Post-Training Map

ASSESSMENT OF POST-TRAINING PROCEDURE USE

Presumably, the superior improvement of the Effective Procedures group over the other groups occurred because these subjects used the trained procedures (hereafter referred to as target procedures). To test this assumption, we scored the questionnaires to determine the frequency of use of procedures before and after training.

Table 3 shows the mean ratings for the use of Effective and Neutral procedures by the three groups. The results confirm that subjects did in fact increase their use of target procedures

Table 3

Mean Reported Frequency of Use of Effective and Neutral Procedures

Group	Before Training	After Training
Effective Procedures		
Effective Procedures group	3.74 *	4.44 *
Neutral Procedures group	3.45	3.72
No Procedures group	4.38	4.23
Neutral Procedures:		
Effective Procedures group	2.18	2.14
Neutral Procedures group	1.96 *	2.53 *
No Procedures group	1.75	1.91

* $p < .05$

after training. The first three rows indicate that Effective Procedure use increased significantly after training for subjects instructed to use those procedures, $t(13) = 2.42$, $p < .05$, but did not increase for the Neutral Procedures or No Procedures groups. Similarly, the Neutral Procedures group reported more frequent use of target procedures on the second map than on the first, $t(15) = 2.31$, $p < .05$. However, use of these procedures did not increase for the other two groups.

To further support the conclusion that the use of the effective procedures improved performance, we computed within-group correlations between the reported use of effective and neutral procedures on the second map and the increment in recall across maps. This increment was measured as the difference in percent recall on the last trial of the two maps. Table 4 shows

Table 4

Correlations Between Mean Use of Procedures after Training and Recall Increment

	Effective Procedures			Neutral Procedures		
Treatment	Complete Elements	Spatial Attributes	Verbal Attributes	Complete Elements	Spatial Attributes	Verbal Attributes
Effective Procedures group	.59 *	.55 *	.42	.16	-.23	-.12
Neutral Procedures group	.31	.32	.08	.17	.06	-.15
No Procedures group	.02	-.05	-.43	.03	-.41	-.54 *

$*p < .025$.

the correlations for recall of complete elements, spatial attributes, and verbal attributes. As expected, the use of effective procedures correlated reliably with improvement in complete element and spatial recall for subjects trained to use these techniques. That is, the more frequently subjects used the effective procedures, the greater their improvement in performance. Three of these procedures (imagery, pattern encoding, and relation encoding) operated on spatial information, while the other three (partitioning, memory-directed sampling, and evaluation) were equally applicable to spatial and verbal information. Therefore, we expected that the correlation between procedure use and performance increment would be higher for spatial attributes than for verbal attributes. As the first row of Table 4 shows, this expectation was confirmed. In contrast, we found no evidence that the use of Neutral Procedures facilitated learning.

VISUAL MEMORY ABILITY

In light of the important role of spatial learning procedures in determining overall learning success, we expected that subjects' visual memory ability would affect success on the learning task. In particular, since imagery and perhaps pattern and relation encoding depend on the use of a visualization process, the effectiveness of training in these procedures might depend on the subjects' ability to visualize spatial configurations in memory.

The analysis of the Building Memory Test scores provided data on subjects' visualization ability. The reliability of this test, estimated by the Spearman-Brown formula, was .76. The mean scores on the 24-item test were 17.61 for the Effective Procedures group, 18.48 for the Neutral Procedures group, and 15.48 for the No Procedures group. An analysis of variance indicated that the groups were indistinguishable in visual memory ability. Across all subjects, the correlations between visual memory and complete element recall (r = .54), spatial attribute recall (r =.55), and verbal attribute recall (r =.44) on the pre-training map were all significant (p < .01). The same correlations between ability and post-training performance were also reliable (r = .63, r = .66, and r = .34, respectively, p < .01).

To determine if training differentially influenced post-training performance for subjects with different visual memory ability, we performed a linear regression of performance increment on training group and ability. Figure 8 displays the increment in recall of complete map elements as a function of ability for each of the training groups. The solid lines represent the best-fitting function for each group, and the dashed lines display the 95% confidence interval for the predicted recall scores. As Figure 8 shows, recall increment increased with ability only for subjects in the Effective Procedures group. We wished to determine for what levels of ability the Effective Procedures training produced significant improvements relative to the other groups. We therefore used the prediction equations to contrast performance increment for hypothetical high-ability (ability score = 24), medium-ability

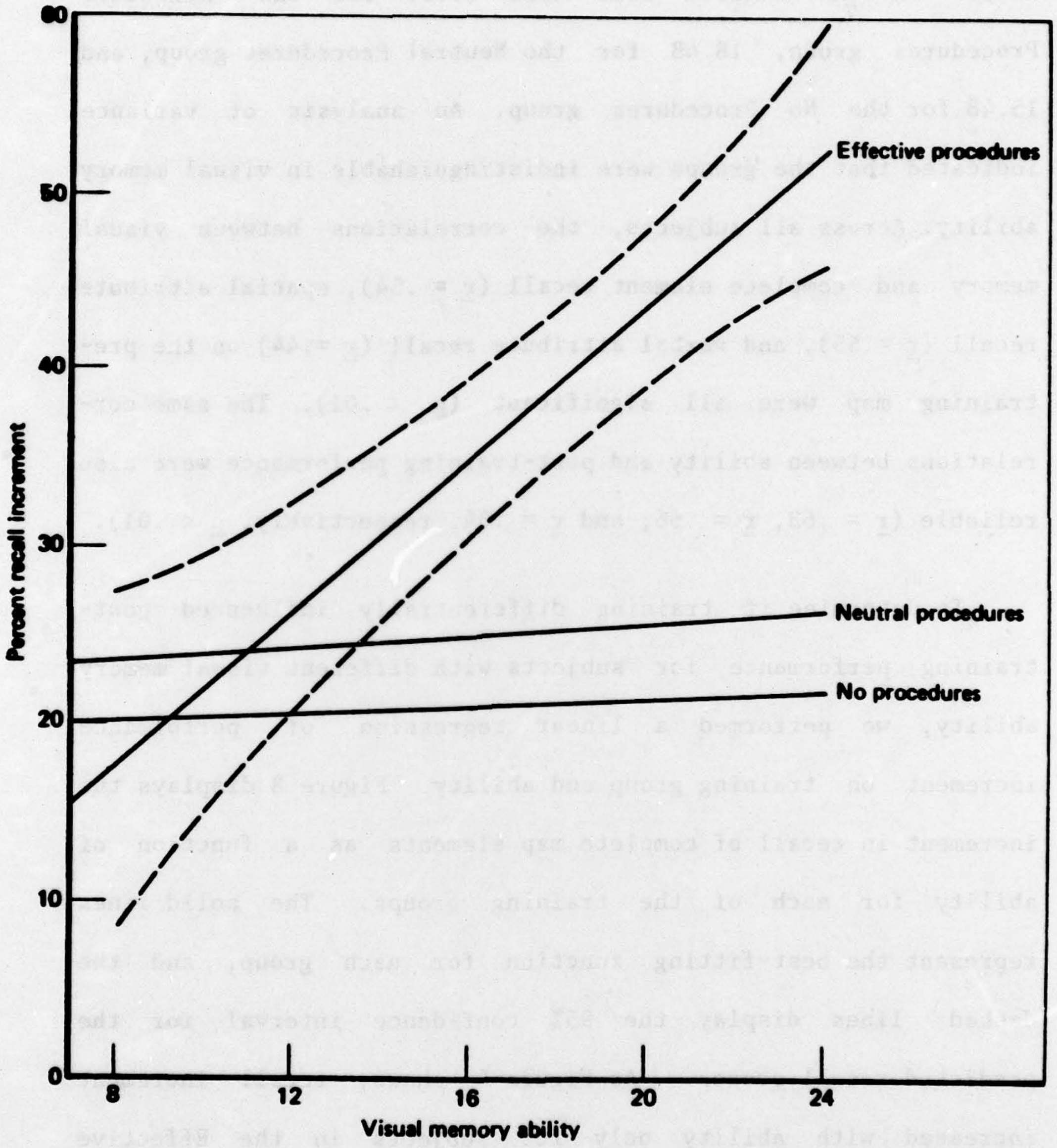

Figure 8. Best-Fitting Regression Line of Recall Increment (Complete Elements) on Visual Memory Ability

(= 17.41, the mean score across subjects), and low-ability (= 10) subjects. For high and medium ability, the increment for the Effective Procedures group was reliably larger than the mean increment for the other two groups ($t(37) = 3.23$, $p < .01$ for high ability, $t(37) = 2.32$, $p < .01$ for medium ability).

Figure 9 shows the increments in recall of spatial (part A) and verbal (part B) attributes as a function of Visual Memory ability. For recall of spatial attributes, the increment for Effective Procedures training was reliably greater than that for Neutral and No Procedures training for high- and medium-ability subjects ($p < .01$ for each). For recall of verbal attributes, the group differences were smaller and were reliable only for high-ability subjects ($p < .05$).

The finding that high-visual-memory subjects benefited most from training suggests that these subjects might have had an advantage over relatively low-ability subjects in successfully using the trained procedures. This advantage could arise from three sources. First, subjects with high visual ability might be more inclined to choose the spatial learning procedures on their own, and thus they presumably would be more practiced at using the procedures. The first two columns of Table 5, however, suggest that this was not the case. The first column gives the correlations across all subjects between visual memory ability and the use of the six effective procedures on the first map, prior to training. The second column gives the same correlations for the subjects in the Effective Procedures group. None of these

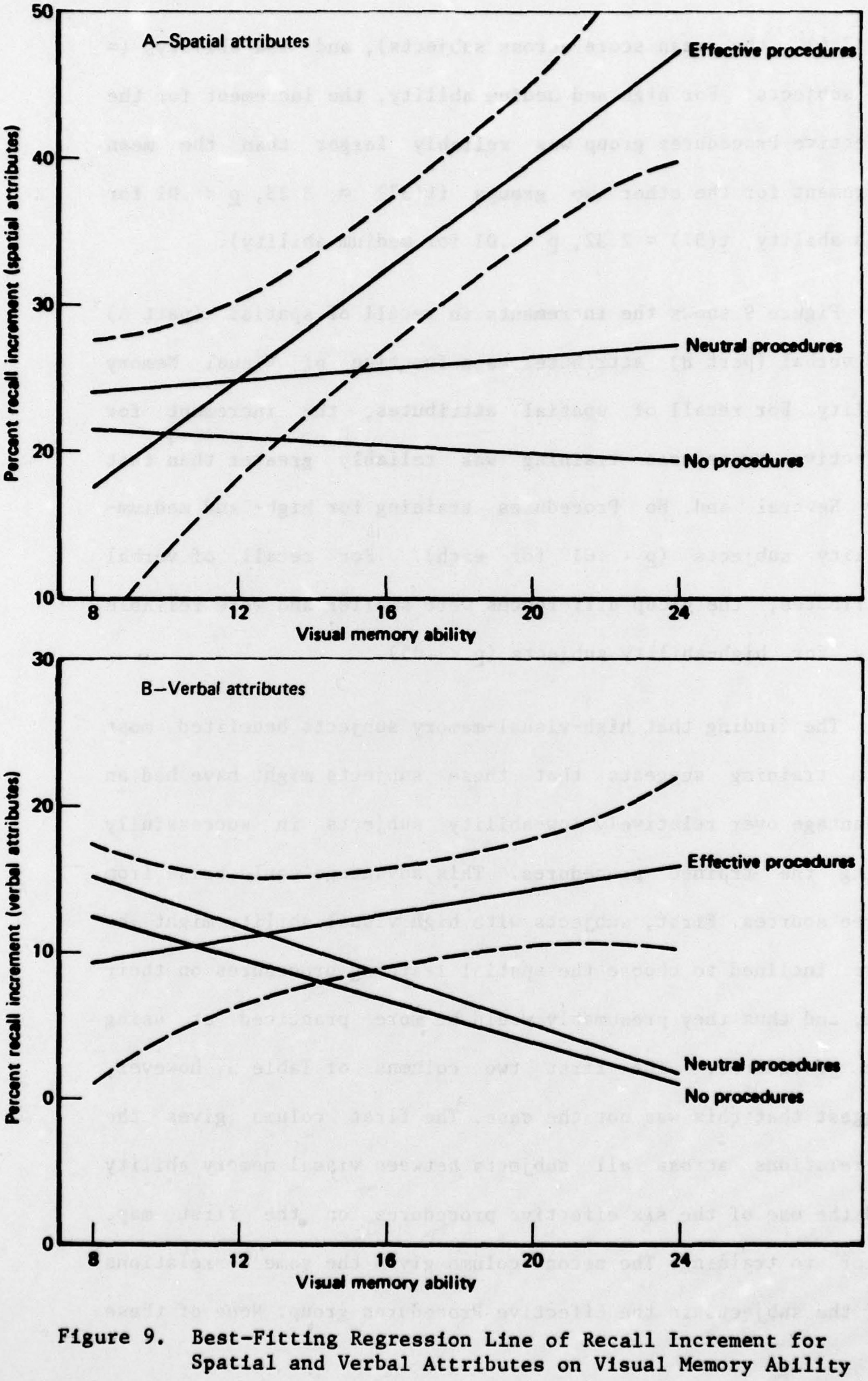

Figure 9. Best-Fitting Regression Line of Recall Increment for Spatial and Verbal Attributes on Visual Memory Ability

Table 5

Correlations between Visual Memory Ability and Effective Procedure Usage

	All Subjects	Effective Procedures Group		
Procedure	Before Training	Before Training	After Training	Increment
Partitioning	-.01	.36	-.23	-.44
Memory-directed sampling	.08	.37	.22	-.30
Evaluation	.07	.27	.35	.15
Imagery	11	.27	.50*	.24
Pattern encoding	.15	.02	.24	.20
Relation encoding	.27	.22	.43	.29

* $p < .05$

correlations is statistically significant. Thus, there does not appear to be a strong relationship between the choice of any effective learning techniques on the pre-test and visual memory ability.

The second possible explanation for the superior improvement of high-ability subjects is that they used the effective procedures more frequently after training than did the low-ability subjects. Subjects with low ability may have been less inclined to follow instructions to use techniques requiring visual memory than subjects with good visual memory. Across all effective procedures, the increment in frequency of use from the first to the second map was uncorrelated with ability (r = .04). However, as the last column of Table 5 shows, this correlation varied for individual procedures. For two of the three non-spatial procedures, low-ability subjects increased their

frequency of use relatively more than high-ability subjects. In contrast, we found positive correlations between increased use of the spatial procedures and ability. Thus, as the third column of Table 5 shows, high-ability subjects used two of the spatial learning techniques considerably more frequently on the second map than did their low-ability counterparts.

Finally, the effectiveness of the spatial learning procedures probably depends on visual memory ability. Subjects with poor visual memory may find these techniques difficult to use successfully. Thus, each use of an effective procedure might be more beneficial for high-ability than for low-ability subjects. To test this hypothesis, we regressed performance increment on visual memory ability and increment in procedure usage across subjects in the Effective Procedures group. When the variance due to the differences in procedure usage was removed from the prediction equation, ability accounted for a significant 27.6% of the remaining variance in performance increment, $\underline{F}(1, 11) = 6.80$, $\underline{p} < .025$.

IV. CONCLUSIONS

It is evident from these analyses that successful map learning depends on particular study procedures for selecting, encoding, and evaluating information. Our previous analysis of learning protocols (Thorndyke & Stasz, 1979) revealed several detailed differences in procedure usage between good and poor learners. Subjects' responses to the procedure questionnaire in the present study replicated these differences. To show that these procedural differences were responsible for performance differences, we attempted to improve map-learning skill by teaching subjects how to use six procedures that we had observed good learners employ frequently. This training did in fact improve subjects' performance relative to subjects who received no or irrelevant training.

While we obtained training-group differences for recall of spatial attributes, the groups did not differ in recall of verbal attributes. Individual differences in recall of verbal information and in the use of verbal learning procedures were much smaller than differences regarding the spatial information. Further, virtually every subject learned more verbal than spatial information on the maps. Because college students typically learn primarily verbal information (e.g., from textbooks, class lectures), they probably develop verbal learning skills and techniques. In contrast, students' relative lack of practice

at learning spatial information may restrict their repertoire of learning techniques and highlight ability differences.

Accordingly, the success of the effective-procedures instruction depended on subjects' visual memory ability. This ability was related both to how frequently subjects used the trained spatial learning procedures and to how successfully they executed them. Low-ability subjects, who presumably have difficulty creating and holding visual images in memory, would have difficulty in using these spatial learning procedures effectively. On the other hand, high-ability subjects could readily use procedures requiring attention to spatial information and the use of imagery. Thus, while high-ability subjects improved tremendously after training, low-ability subjects improved no more than subjects in the other training groups.

While both learning procedures and abilities appear to be important contributors to performance, we cannot yet assess their relative importance. Additional research is required to investigate whether subjects with relatively low visual memory ability may be taught to employ spatial learning procedures effectively. This question hinges on the precise relationship between the low-level processes required to perform psychometric tests of visual ability and those required for the use of high-level procedures. Some very basic spatial abilities, such as visualization, may consist of one or a few elementary processes. We view learning procedures as program-like combinations of these low-level processes. Visualization, for example, may be a single

component of a more complex procedure, such as evaluation. This procedure may require the visualization of information in the current focus of attention.

Traditionally, psychologists have viewed abilities as general traits relatively resistant to change. Many learning procedures, however, are presumably flexible skills that are trainable and may improve with practice (cf. Hasher & Zacks, 1979). Therefore, if low-visual-memory individuals cannot readily be taught to use spatial learning procedures effectively, then it would appear that their use is highly ability-dependent. For these individuals, optimal instructional design might capitalize on other learner aptitudes. For example, learners might be taught to use procedures that depended on processes they were skilled at using. Subjects themselves appear to be particularly adept at selecting strategies that are well-suited to their abilities (e.g., MacLeod, Hunt, & Mathews, 1978). On the other hand, if subjects of all abilities, given sufficient training, can learn spatial processing techniques, current assumptions about the nature of abilities and their explanatory power as a stable source of individual differences would be seriously challenged.

Our findings may have signficant implications for the design of map training courses for the military. Since the use of effective processing procedures can significantly improve the amount and rate of map learning, instruction in the use of such procedures might provide a successful training vehicle.

Furthermore, these procedures might be useful in other military map-using tasks as well.

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